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Project No. 7222
Task No. 71712

WRIGHT AIR DEVELOPMENT DIVISION
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report covers part of the experimental research on the effects of acceleration on the control and performance of high performance air-and spacecraft being conducted by the Biophysics Branch, Aerospace Medical Division of Wright Air Development Division under Research and Development Project 7216, "Biophysics of Acceleration," Task 71712, "Biophysics of Circulation," with Dr. E. P. Hiatt acting as project monitor.

The author is now employed by Cornell Aeronautical Laboratory, Inc., Cornell University, Buffalo 21, New York.

ABSTRACT

Measurements are reported on the effects of moderate acceleration upon the absolute thresholds of foveal (cone) and peripheral (rod) vision.

This experiment shows that accelerative stress has a consistent and progressive effect on visual performance, this effect being proportional to the magnitude of the positive acceleration.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

ANDRES I. KARSTENS
Colonel, USAF (MC)
Chief, Biomedical Laboratory

INTRODUCTION

The purpose of this study was to quantify the dimming of vision that occurs in the range of 3 to 4 g in the unprotected subject, and to observe in detail the changes in brightness vision that occur in the central and peripheral retina. Dislocation of the visual function by acceleration was studied selectively by the use of anti-g suits. As a protective device, these suits aid in maintaining normal retinal blood flow, but offer no protection against direct mechanical effects on the eye. The general thesis of this study was that visual thresholds offer a practicable, quantitative index of accelerative stress.

METHOD

Absolute threshold was selected for measurement because of (1) the demonstrable changes this function undergoes with physiological stress, (2) the availability of photometric equipment sufficiently precise and sensitive to record shifts in visual performance; and (3) the relative constancy of the threshold of the dark adapted eye.

Apparatus. The Wright Air Development Center human centrifuge used in this study produces acceleration in exactly the same manner as does a turning aircraft. A rotating boom moves a carriage around in a horizontal circle, the carriage being free to pivot on a horizontal axis tangent to the circle of rotation of the boom. As the speed of the boom increases, the bottom of the cab swings outward and upward toward the horizontal. Thus the acceleration is approximately parallel to the long axis of the subject's body.

A modified Hecht-Shlaer adaptometer (4) was used to measure visual thresholds. This instrument permits an exact specification of the luminance, duration, color and size of the test flash. The location of the test flash on the retina is controlled by having the subject look at a fixation light. Luminance of the light flashes is controlled and adjusted by an optical wedge which is employed either alone or in combination with neutral filters.

Several modifications were made to the adaptometer: (1) an automatic sensing of the intensity of the light each time the shutter was opened, (2) a recording system, remote from the adaptometer, (3) an automatic presentation of the stimulus flash once every second, and (4) a combination of automatic and subject control of the intensity of the stimulus flashes. The chief advantage of these modifications was that the subject could determine his own threshold. This principle of operation is not unique; it has been used successfully to determine auditory and visual thresholds with both humans and pigeons as subjects (4). The apparatus used in the study is pictured in Figures 1 and 2. In the last figure the subject is pictured with the lightproof, ventilated, head size dark room made for the study. This enabled the safety observer who rode in the center of the centrifuge to see the subject at all times by means of the room lights.

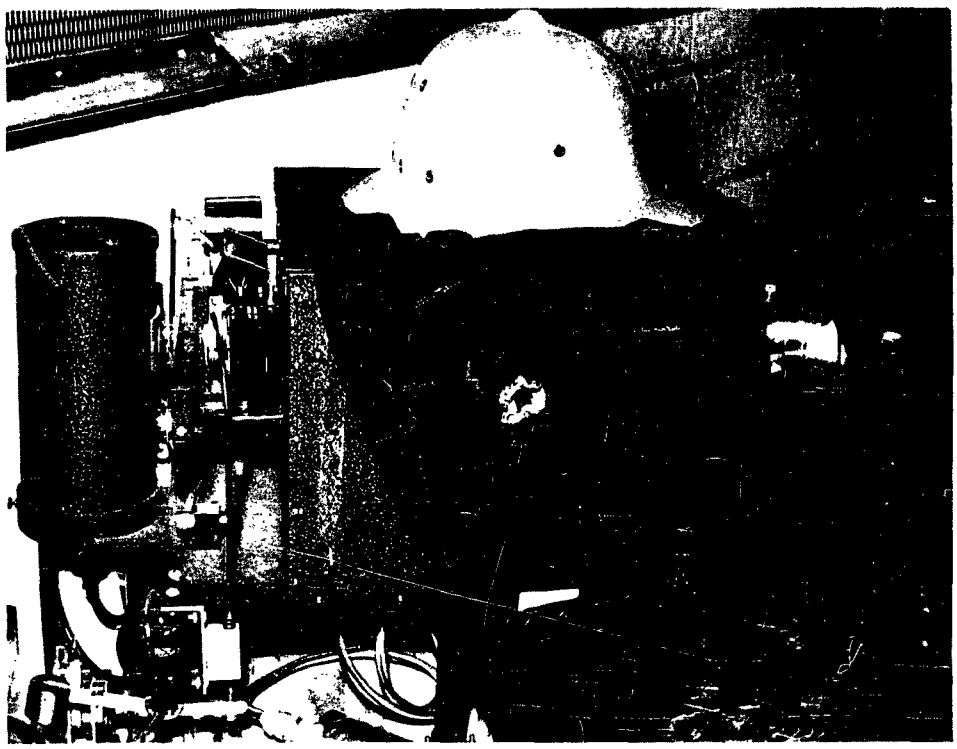

FIGURE 1. ADAPTOMETER AND DARK ROOM USED IN THE EXPERIMENT ON VISUAL THRESHOLDS

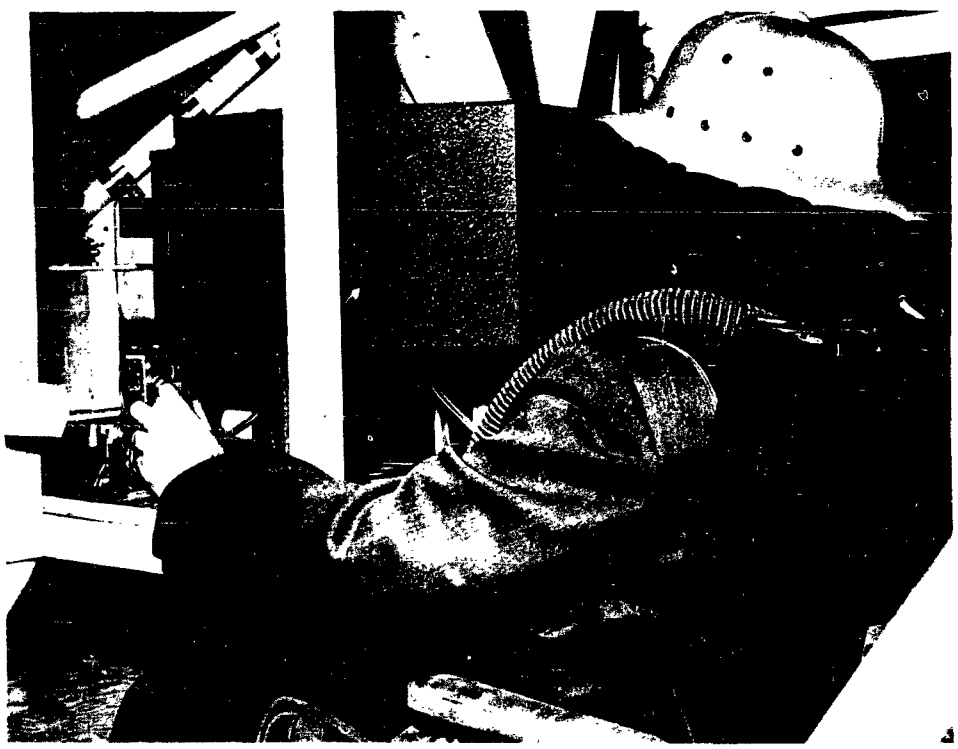

FIGURE 2. SUBJECT SEATED IN THE TESTING POSITION

Discriminations made by the subject during an experimental session were recorded on a photoelectric pen writer located outside the centrifuge. These records were later viewed and put in digital form for computer analysis. Equipment failure resulted in the discard of 4 runs out of the more than 100 runs that were made.

Procedure. Preparation for this experiment was begun by having the subject make almost daily determinations of his foveal and peripheral thresholds. This training period lasted almost two weeks, each training session lasting one hour. At the end of each session the graphic records were reviewed by the subject.

The test procedure for measuring thresholds during the experiment was a modification of the psychophysical method of limits (3). That is, the subject is told to increase the luminance of the test flash until he sees the light and then to decrease the luminance until the flash can no longer be seen, etc. In this way the luminance of the test flash is made to oscillate around the threshold of the subject during the course of an experimental run. The amplitude of these oscillations is a measure of the difference limen for luminance at the absolute threshold. This method was adopted because of its efficiency. It is especially advantageous in situations where a maximum amount of data is required and the test periods are constrained by consideration of subject comfort, human tolerance, etc. This procedure also differs from the classical method in that the subject begins an experimental run by increasing the luminance of the stimulus flashes. In this manner the adaptation of the visual system is not disturbed appreciably by the minimal exposures to light needed to determine the threshold.

Experimental runs lasted one minute, fifteen seconds and were spaced two minutes apart. During a run, approximately 14 alternate ascending and decending threshold determinations were made. In some runs, especially those at maximum acceleration, the number of determinations was somewhat less than this, but never less than 8. This was, in part, because it required a longer time to reach the 3 and 4 g levels. However, still another factor served to limit the number of responses made in experimental runs; threshold measurements obtained during the onset of g were not counted. The criterion was established that only thresholds obtained after peak g would be considered as data for this study. The rate of onset of acceleration was 1 g every 1-1/2 second. This rate was selected to produce maximum visual effect, while the duration of the runs were selected to reflect fluctuation in circulatory physiology concomitant with an increase in the force environment.

Four levels of acceleration were used in this experiment. The 1 g or static condition served as the baseline for measurements at higher g levels. The upper g limit was set by the relation between peripheral light loss and the average acceleration required to produce this symptom. We already know that at high g values all visual functions will be impaired.

It was therefore decided, for the purpose of this study, that the highest g value to be used would remain at least 0.5 g below that value at which peripheral light loss would occur.

Foveal thresholds were measured with a red test patch 3° in diameter. A small red fixation point was placed so as to coincide with the center of the test field. In making these measurements and those in the peripheral retina, a test flash of one-fifth second duration was adopted. Measurements made on a retinal area 3° in diameter, located 7° temporally on the retina, with a purple test light, are referred to as peripheral threshold data. The fixation light and colored filter were those supplied with the adaptometer. Subject was dark adapted 30 min for foveal thresholds and 60 min for peripheral thresholds.

The technique and procedure for measuring threshold was the same for each test condition. The plan of the experiment called for an initial series of calibration runs used for aligning the luminance scale with the scale on the pen writer and defining the subject's level of visual adaptation. Complete adaptation was recognized when five successive threshold measures showed less than 0.1 log unit variation. Each run lasted for 1 minute, 15 seconds and was followed by a 2 minute period of rest. A verbal signal given to the experimenter began and ended each run. Runs to be made at increased g were started coincident with the rotation of the centrifuge. These runs were of 1 minute, 15 seconds duration with the last minute of the run at maximum acceleration. Variations in this schedule were few and necessitated by unavoidable interruptions.

In planning the experiment, provision was made for obtaining data at 1 g static following repeated runs at 2, 3, and 4 g. Systematic effects were anticipated since the sequence of runs was always from 1 g to a higher level. Ten runs were made at each level of acceleration with the fifth run as a control run. Some variations also occurred in this schedule but they were not judged to be important. The procedure for a run with anti-g suit protection did not differ from those outlined above.

Subject. The one subject used in this experiment was a seasoned observer with considerable experience in riding the centrifuge and in participating in psychophysical experiments.

RESULTS

A summary of the major results of the experiment is shown in Table I. The means of the threshold determinations made on the dark adapted fovea and on a retinal region displaced 7 degrees from the fovea differ by several log units, under normal conditions, and serve to demonstrate the dual nature of the adaptive process. Each datum of log luminance threshold is based on a different number of determinations. The number on which the mean is based is shown in the following table.

TABLE I

MEANS AND STANDARD DEVIATIONS OF THE LUMINANCE THRESHOLD DATA BY RETINAL POSITION AND ACCELERATION (LOG MICROMICROLAMBERTS)

RETINAL POSITION	ACCELERATION	MEAN	S.D.	N
FOVEAL	1	6.658	$\bar{1}$.75	52
	2	6.756	$\bar{1}$.70	76
	3	6.923	$\bar{1}$.89	120
	4	7.189	0.67	128
PERIPHERAL	1	3.352	$\bar{1}$.53	66
	2	3.488	$\bar{1}$.69	112
	3	3.787	$\bar{1}$.34	110
	4	3.923	0.53	78

The results of an analysis of variance performed on the data are shown in Table II. This analysis was performed in terms of the optical wedge scale, the units of which are used to record the intensity of the test light. All statistical analyses were made and are reported in this unit of measurement. Conversion to density units and thence to luminance was performed according to the conversion sheet supplied with the adaptometer.

TABLE II

SUMMARY OF ANALYSIS OF VARIANCE FOR ABSOLUTE LUMINANCE THRESHOLD DATA OBTAINED IN CENTRAL AND PERIPHERAL RETINA

	FOVEAL			PERIPHERAL		
SOURCE OF VARIANCE	df	MEAN SQUARE	F	df	MEAN SQUARE	F
ACCELERATION	3	350.6190	66.95^{xx}	3	302.6092	136.91^{xx}
TRIALS	29	5.2371	6.55^{xx}	27	2.2103	6.11^{xx}
OBSERVATIONS	333	.7994		335	.3618	

x. $P < .05$
xx $P < .005$

Examination of the F ratios in Table II shows that acceleration and the number of the experimental run make significant contributions to the variance of the threshold measurements.

Table III summarizes the results of an analysis made of the difference between mean thresholds obtained at 1 g and at higher acceleration levels. All comparisons gave statistically significant results.

TABLE III

SIGNIFICANT INDIVIDUAL "t" TESTS OF THE ABSOLUTE THRESHOLD

FOVEAL	PERIPHERAL
$\|G < 2\ G^{x}$	$\|G < 2\ G^{xx}$
$\|G < 3\ G^{xx}$	$\|G < 3\ G^{xx}$
$\|G < 4\ G^{xx}$	$\|G < 4\ G^{xx}$

x $P < .05$ BASED ON A ONE SIDED "t" TEST WITH 29 AND 27 DEGREES
xx $P < .005$ OF FREEDOM

During all experimental runs a minimum of eight ascending and descending determinations of threshold were made. This sequence was subdivided to include the first four determinations and determinations 7 through 10. The first of these determinations came during the first seven seconds after reaching peak acceleration. This relation is shown in more detail in Table IV. Determinations 7 through 10 correspond with the 20th to 30th second of a run. A comparison of the mean thresholds (summarized in Table V) when computed in this way provided two significant mean differences, one for each retinal position, at the 4 g level.

TABLE IV

AVERAGE TIME BETWEEN REACHING MAXIMUM G AND THE 1st TRANSITIONAL RESPONSE
(all values in seconds)

ACCELERATION	FOVEAL	PERIPHERAL
1		
2	6.84	7.88
3	7.00	6.38
4	7.12	8.52

TABLE V

ABSOLUTE LUMINANCE THRESHOLDS OF THE CENTRAL AND PERIPHERAL RETINA BASED ON DETERMINATIONS 1 THROUGH 4 AND 7 THROUGH 10

ACCELERATION IN G UNITS	RETINAL POSITION			
	FOVEAL		PERIPHERAL	
	1 - 4	7 - 10	1 - 4	7 - 10
1	6.658	6.680	3.352	3.333
2	6.735	6.746	3.474	3.501
3	6.923	6.923	3.787	3.787
4	7.222	7.123^{xx}	4.018	3.869^{xx}

x $P < .05$
xx $P < .001$

Table VI summarizes the relation between log luminance threshold of the peripheral retina at different levels of stress under two conditions of protection. Anti-g suits provide a counterpressure to the lower half of the body when the g valve is activated. Valves are designed to inflate the suit at 2.4 g and above. Thus, a functional relation could not be obtained at levels less than that value.

TABLE VI

ABSOLUTE LUMINANCE THRESHOLDS OF THE PERIPHERAL RETINA UNDER TWO CONDITIONS OF G PROTECTION

CONDITION	ACCELERATION IN G			
	1	2	3	4
NO SUIT	3.35	3.49	3.79	3.92
CSU - 3/P SUIT	G VALVE OPENS AT 2.4G AND ABOVE		3.57	3.69
FULL BLADDER SUIT			3.65	3.66

Figures 3, 4, and 5 show a graphic summary of the data of this experiment.

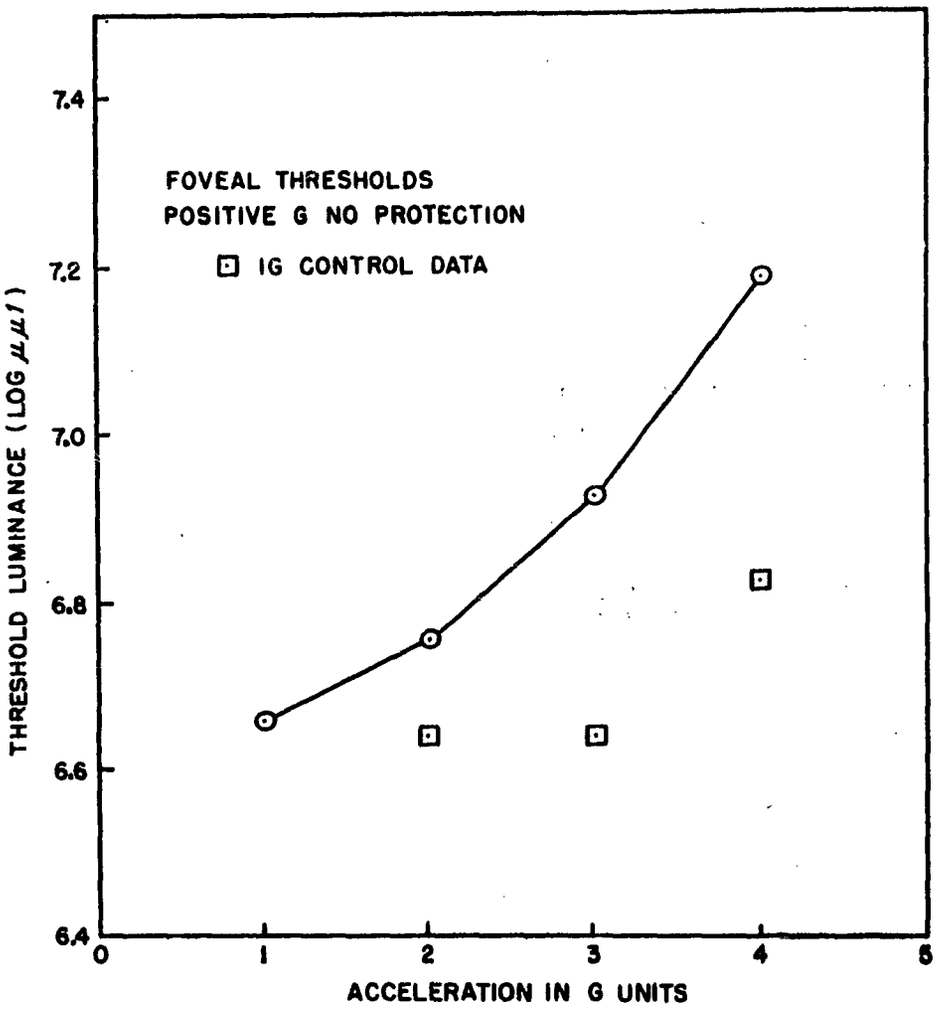

FIGURE 3. FOVEAL THRESHOLDS AS A FUNCTION OF ACCELERATION.

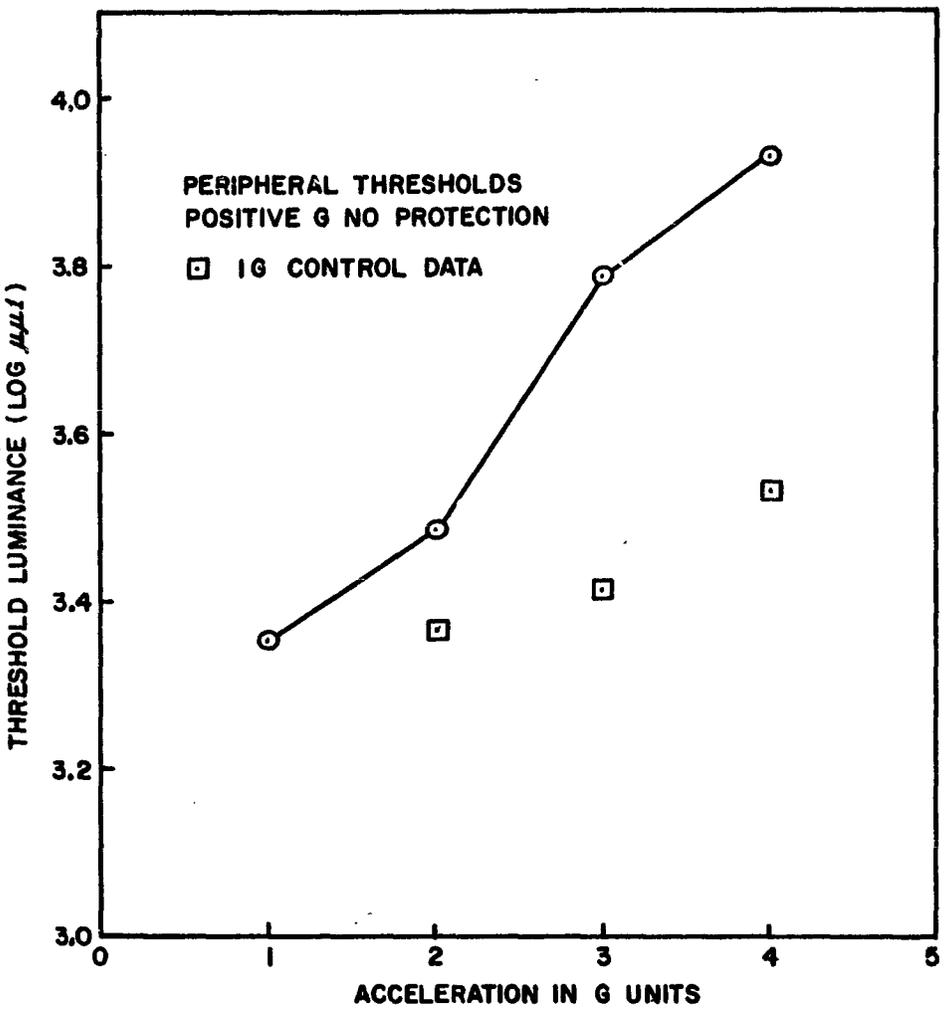

FIGURE 4. PHERIPHERAL THRESHOLDS AS A FUNCTION OF ACCELERATION.

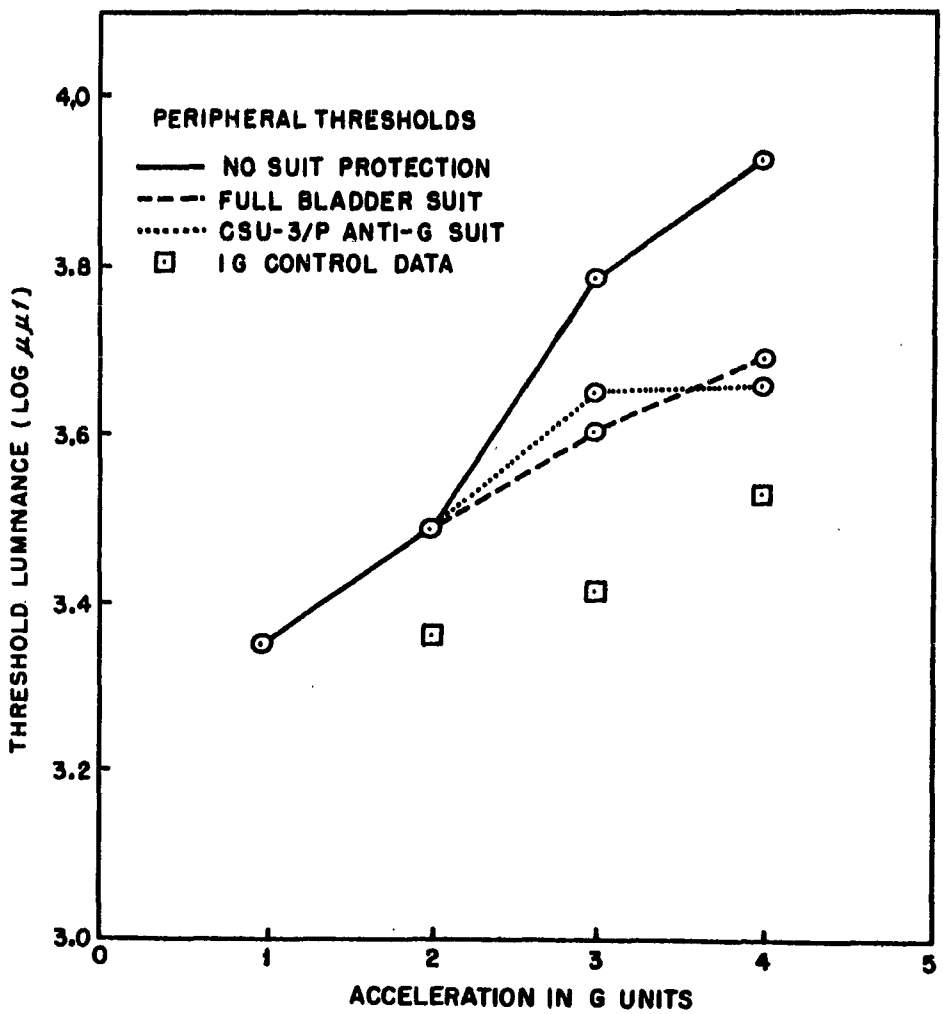

FIGURE 5. THE INFLUENCE OF TWO KINDS OF G PROTECTIVE EQUIPMENT ON PHERIPHERAL THRESHOLDS.

DISCUSSION

The objectives of this experiment were, (1) to quantify the phenomenon of visual dimming, (2) to determine with what sensitivity visual threshold measures reflect changes in circulatory physiology, and (3) to explore the interaction of two different types of g protective equipment on visual thresholds during acceleration.

With regard to the first objective, the experiment shows not only whether or not a light can be seen, but also the intensity necessary to be seen at given levels of probability and of acceleration. The absolute thresholds of the dark adapted fovea rose with increasing g to new levels, 0.5 log units above normal. Foveal threshold measurements, made while the subject was riding at 3 g, almost double those at 1 g. At 4 g, thresholds had risen to a level where the intensity of the stimulus light had to be increased 3.4 times in order to be seen at the 50 percent probablility level. Measurements made in the periphery of the retina showed similar changes with acceleration, differing only in the final level. For example, the rise in threshold at 2 g was 1.5, at 3 g the factor was 3.0, and at 4 g the factor was 4 times the 1 g value.

The second objective was concerned with the sensitivity of threshold measures to haemodynamic changes that occur during acceleration. It is beyond the scope of this paper to discuss in detail the circulatory changes that occur during acceleration. However, a paper by Henry, et al (5), on blood pressure recordings taken at eye level during acceleration is germane to this discussion. Their records show that blood pressure falls with the onset of g, the size of the drop being proportional to the acceleration. A run at 4 g would produce blood pressure, at eye level, of 1 to 2 mm Hg. This depression in pressure is followed by a gradual increase, and after 7 to 10 seconds at peak g, the pressure is sustained above the level of visual symptoms.

One of the analyses performed was for the purpose of detecting the effect of these transient changes in blood pressure on threshold. Table V indicates the success in achieving this objective. The difference in mean, absolute thresholds when computed on the basis of determination taken during the first 10 seconds of the run and when based on determinations as late as 30 seconds in the run, is significant only at 4 g for both retinal test areas. The inability of the test to reflect physiological changes at lower levels of acceleration is probably caused by human failing. Thresholds cannot be obtained at rates commensurate with physiological changes.

Visual symptoms have become the measure of anti-g suit efficiency. The suits used here were selected because of their different effects on vision (7). In one, the entire lower half of the body is encased in a pneumatic bladder.

Inflation of the suit produces an even counterpressure over a large part of the body. The other suit, identified as the CSU-3/P, gives g protection by applying pressure over five critical anatomical locations in the legs and abdomen.

The ability of the protective equipment to maintain lower thresholds than those obtained without it was expected. The magnitude of the protection was somewhat less than that anticipated on the basis of blood pressure recordings made at eye-level. A more detailed study is needed in which visual thresholds are obtained as a function of anti-g suits, protective body positions, and drugs.

Sequence effects were expected and steps were taken to measure their effect on the threshold data. Runs at increased g were divided so that every fifth run was taken at baseline (1g) conditions.

These control data were obtained two minutes after each preceding run, an interval judged to be sufficient for post-g effects, if any, to have disappeared. Control data show that two minutes after exposure to 4 g positive the average threshold was displaced upwards. This rise in threshold indicates a loss in visual sensitivity.

A second type of sequence effect was examined by means of the analysis of variance. The schedule used in this experiment called for a sequence of ten runs at any given acceleration level. The sequence began and ended with a 1 g control run and with a control run midway in the sequence. Of concern here are the accumulated effects of riding at increased g. The analysis of variance showed that such effects were present and statistically significant. A graphic analysis indicated that the threshold level increased with frequency of runs. This rise in threshold was small compared to the effects of acceleration on threshold. A plot of the standard error of the mean for each acceleration did not include an overlap between scores obtained at different g levels. Neither the cumulative nor post-g effects were observed 24 hours after an experimental session.

In this connection it is interesting to note the possiblity of a dual explanation for the observed changes in threshold. If sequence effects are ignored it is then possible to interpret the results in terms of retinal ischemia. Since the subject was kept wholly dark adapted, andthe photochemical system of the receptors therefore stationary, the threshold changes may be assumed to have originated in the neural system of the eye. Secondary effects (post-g and accumulative) might reflect changes in the chemical regeneration cycle of the photopigments of the eye. It is fairly well established that oxygen is critical to the replenishment of this material and that oxygen deprivation produces slower rates of regeneration.

The data from this experiment may be compared with similar data obtained during experimental hypoxia. McFarland and Forbes (6) found the rise in peripheral thresholds to be 3 times normal in subjects exposed to 10 percent oxygen. This is an oxygen saturation roughly equivalent to 17,000 feet altitude.

SUMMARY

The purpose of this study was to observe in detail the changes in brightness vision that occur in central and peripheral retina during moderate acceleration. Measurements were made of the absolute threshold of foveal (cone) and peripheral (rod) vision within the range of 1 to 4 g. Dislocation of the visual function was studied selectively by the use of anti-g suits.

The following basic findings resulted from an analysis of the data gathered from these experiments:

1. Acceleration levels of 3 and 4 g approximately double and triple foveal thresholds.

2. Threshold levels in peripheral vision triple at 3 g and quadruple at 4 g.

3. A rise in threshold (decline in visual sensitivity) is found with repeated exposure to acceleration, the rise being smaller than that associated with acceleration.

4. The rise in peripheral thresholds is, in part, compensated for by anti-g suits.

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